DIFFERENT

not difficult

Welding

Soldering Aluminum

Brazing

REYNOLDS

METALS CO.

DIFFERENT . . . NOT DIFFICULT

Foreword: This booklet is for use as a supplement to the Reynolds Metals motion picture, "ALUMINUM WELDING . . . Different, Not Difficult". It reviews the technical information presented in that movie and supplements it with additional details. The aim here is to provide an understanding of the basic fundamentals of the most important welding, brazing, and soldering processes used for joining aluminum.

CONTENTS

THE OXIDE COATING 3

HIGH THERMAL CONDUCTIVITY 5

NO HEAT COLORS 6

PROPER MECHANICAL SUPPORT 10

WELDABILITY RATINGS .. 10

FRICTION SOLDERING 13

FLOW SOLDERING 14

BRAZING PROCESSES 15

— Torch Brazing 15

— Furnace Brazing 16

— Dip Brazing 16

FUSION WELDING PROCESSES 17

— Torch Welding 18

— Arc Welding 18

— Shielded Tungsten Arc (Tig) 18

— Shielded Metal Arc (Mig) 18

— Coated Rod 19

RESISTANCE WELDING PROCESSES 20

— Flash Welding 21

— Stud Welding 22

— Spot Welding 23

PROCESS DEFINITIONS 25

1958

©REYNOLDS METALS COMPANY

Richmond 18, Virginia

THE WELDING, SOLDERING, AND BRAZING OF ALUMINUM

BACK IN THE horse-and-buggy era of joining aluminum, little was known about the various factors involved and no equipment especially designed for aluminum was available. However, those days have long since gone into limbo and today it is just as easy to join aluminum as any other metal. Welding, brazing, or soldering aluminum is not difficult. . . . it is just different. . . . as will be shown.

The state of our technological advance today is such that all the factors entering into the welding, brazing, and soldering of aluminum are well known. Special methods and equipment have been perfected which today make aluminum one of the most easily joined of all our metals. And new methods still under development promise still futher contributions to increasing speed and quality while reducing costs.

For evidence that aluminum is truly one of the most easily joined of all metals, see the process chart, Fig. 1. Here are 34 different methods which have been found suitable for joining aluminum. Those most widely used appear in heavy circles. The basic processes detailed in this handbook have page numbers shown in the index on Page 2. For definitions of these various methods, see Page 25. The many processes in use indicate that "Joining aluminum is not difficult . . . . it is just different".

But it is most important to fully understand the things that make aluminum different. So before we look at any of the joining methods, let's first examine the characteristics that set aluminum apart from other metals.

OXIDE COATING

Aluminum has a great affinity for oxygen. In fact, aluminum is so active chemically that it reacts with the oxygen in the air instantly to produce a thin, hard, glasslike film of aluminum oxide on the surface of the metal. It has been said that no one has ever seen aluminum because what you are actually looking at is the thin transparent oxide film that normally covers the metal at all times.

It is primarily the presence of this oxide film that makes the joining of aluminum different. Obviously a layer of glass between two metal surfaces would prevent fusing them together. This, in effect, is exactly what the oxide film does.

So, first, this film must be removed. There are several possible methods. It can be scraped off mechanically with a sharp tool, a wire brush, sandpaper, or similar means of mechanically abrading the surface. It can be dissolved chemically by a flux. Or a chemical reaction can replace the oxide with another material that will not hinder bonding. The intense heat of the electric arc will vaporize the oxide film . . . . All these methods are practical and are in use today.

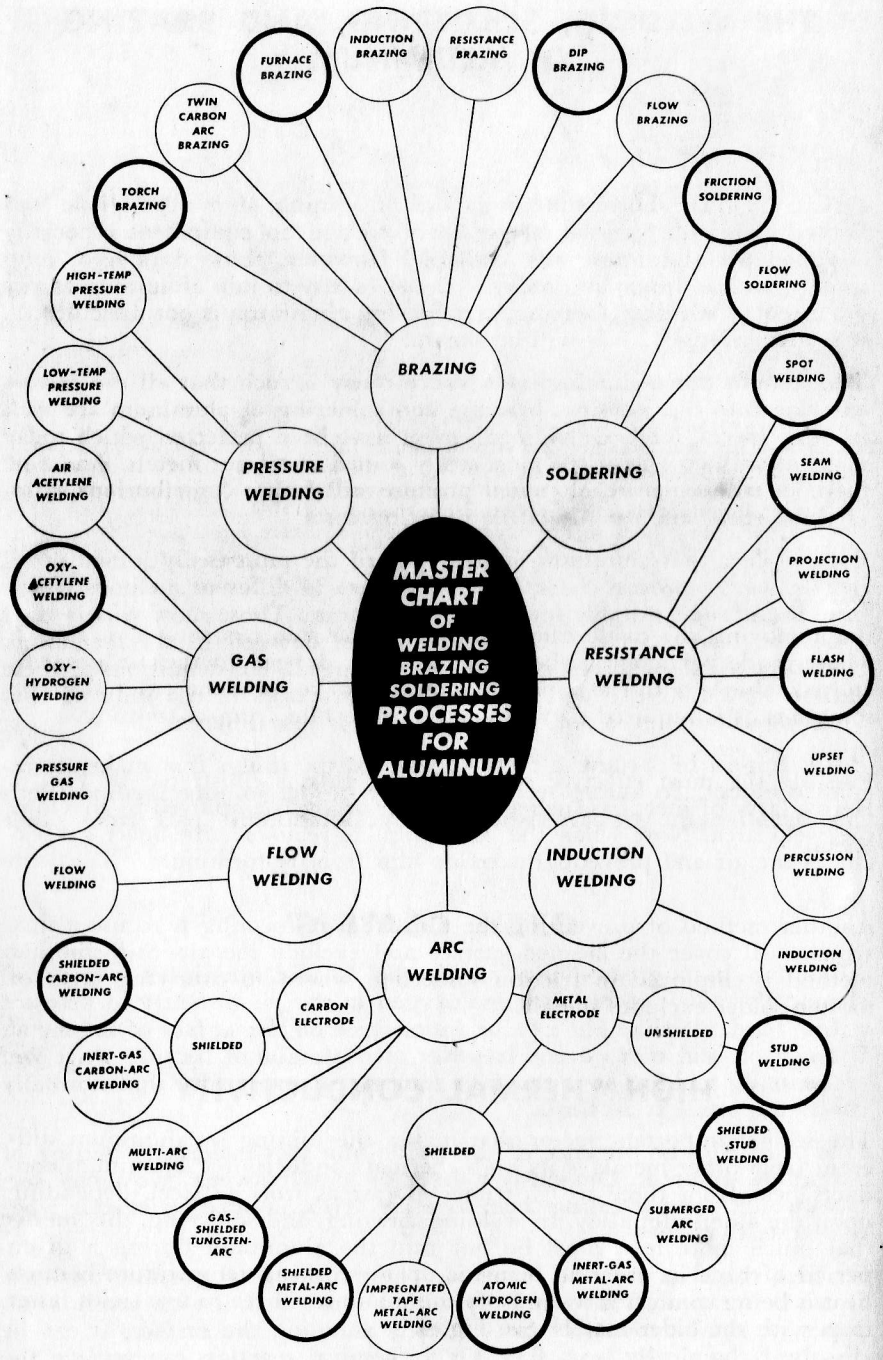


Fig. 1 — Here are 34 processes suitable for joining aluminum. Those in the heavy circles are most widely used. For page numbers of processes discussed in this handbook, see index, Page 2.

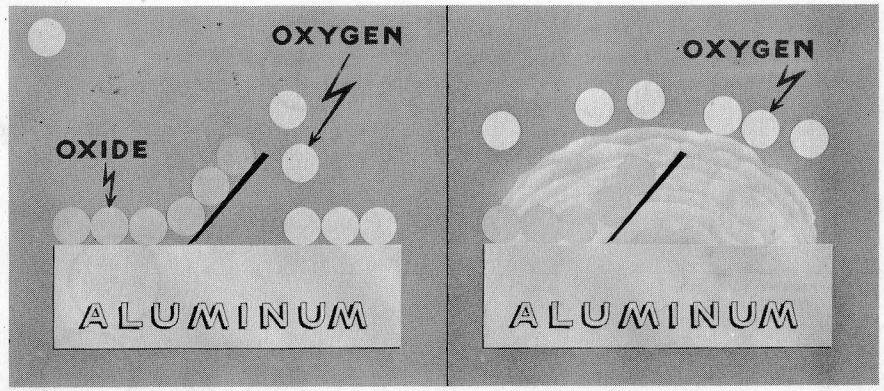


Fig. 2,3 — This diagram shows how oxide film re-forms immediately as it is scraped off under ordinary conditions where the aluminum surface is exposed to the atmosphere. At the right, the presence of an inert gas enveloping the aluminum surface prevents re-formation of the oxide film when it is removed, because the oxygen of the atmosphere is excluded.

But removing the oxide film is only the first step. As shown in Fig. 2, where oxide particles are being scraped off, oxygen in the air immediately combines with the exposed aluminum to re-form the oxide skin. So some means is required to prevent the oxide film from re-forming.

Possibly the most effective way of doing this is illustrated in Fig. 3. Here a layer of inert gas such as helium or argon is employed to envelope the weld area. Now when the oxide film is removed, the inert gas excludes the air and prevents the oxide film from re-forming.

Another method of preventing the film from re-forming is to use a flux which will cover the cleaned surface and exclude the air. Still another method is employed in friction soldering, where an overlying layer of molten solder excludes the air.

HIGH THERMAL CONDUCTIVITY

The second important factor that makes the joining of aluminum different from other metals is its high thermal conductivity. Aluminum conducts heat from three to five times as fast as iron or steel, depending upon the aluminum alloy. In welding, brazing, and soldering, this means that much more heat must be put into the aluminum during a given period of time in order to bring it up to working temperature because heat is being conducted away from the joint area three to five times faster than with the older metals. See Fig. 4.

This is why attempting to solder aluminum with a soldering iron is not recommended as most ordinary irons simply do not have enough heat output. So a torch is recommended as a heat source for soldering aluminum. Similarly, in torch brazing and torch welding, again provision

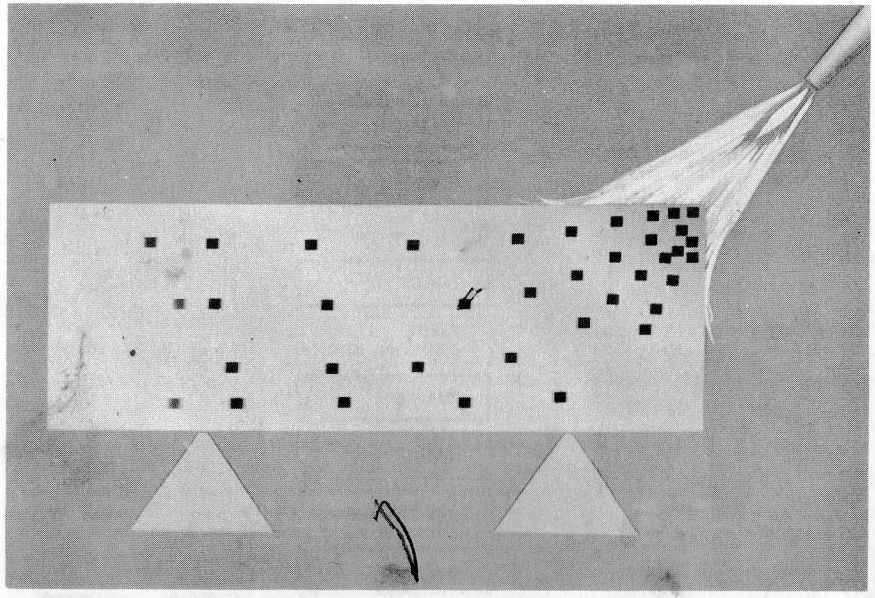


Fig. 4 — The high thermal conductivity of aluminum means that it conducts heat rapidly away from the joint area. To overcome this, a high input is indicated and rapid joining methods preferred. Also "point" supports should be used to prevent draining off heat.

must be made for greater heat input to the work . . . . usually obtained by using a slightly larger tip orifice. This is also the reason why the intense heat of the electric arc is so well adapted to welding aluminum.

This high heat conductivity is also why welding, brazing, and soldering procedures emphasize completing the joint as fast as possible, because speed cuts down the amount of heat that is conducted into the surrounding area and thus reduces any tendency toward warping and distortion.

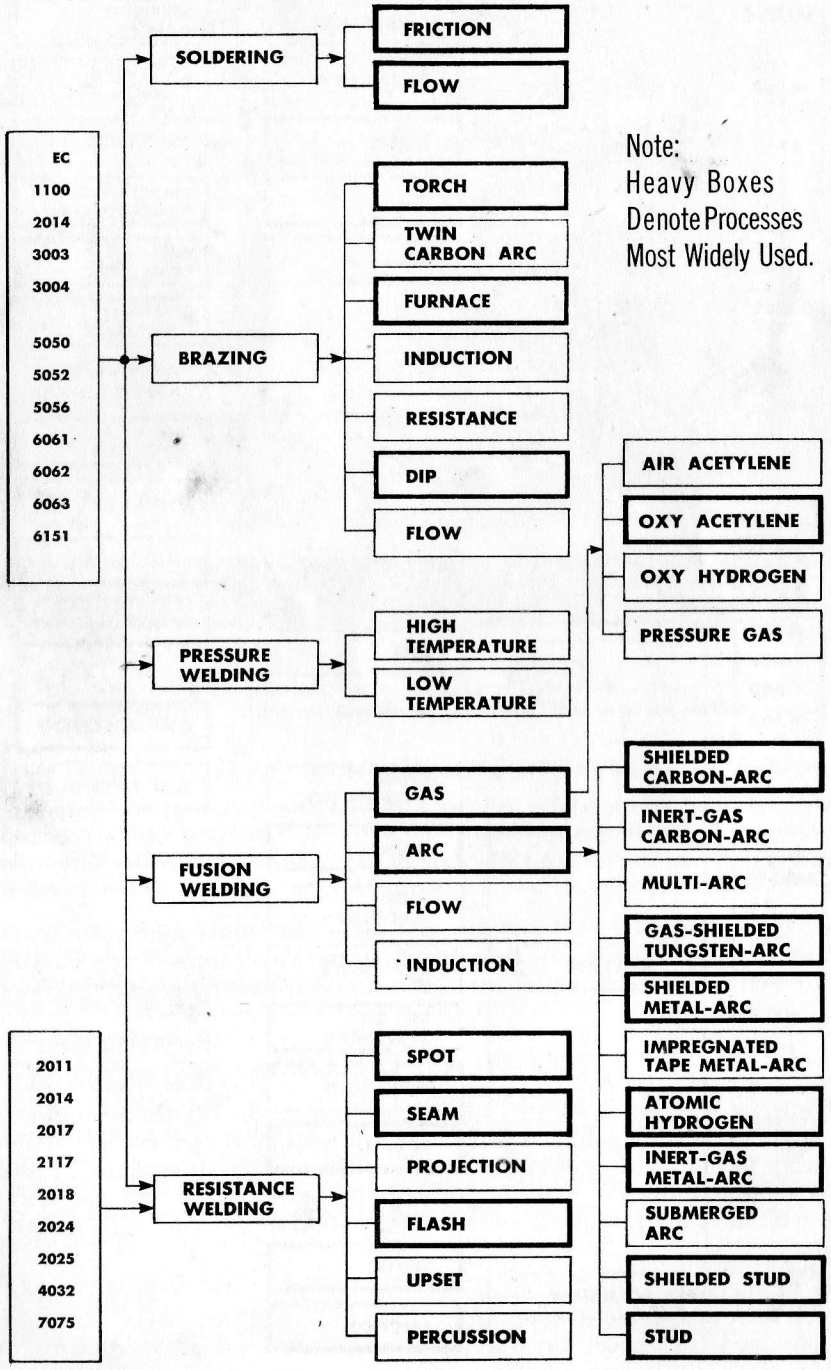
This factor also makes it important to use "point" supports for the work, as any large flat areas contacting the aluminum will drain heat off rapidly, in turn requiring a greater heat input to complete the joint. See Fig. 4.

NO HEAT COLORS

In contrast to working with iron or steel which reveals its temperature throughout a wide range by its color, aluminum shows no heat color even up to the melting point. It is only when molten aluminum is raised considerably above the melting point that it glows a dull red. So working with aluminum requires some other method of determing its temperature.

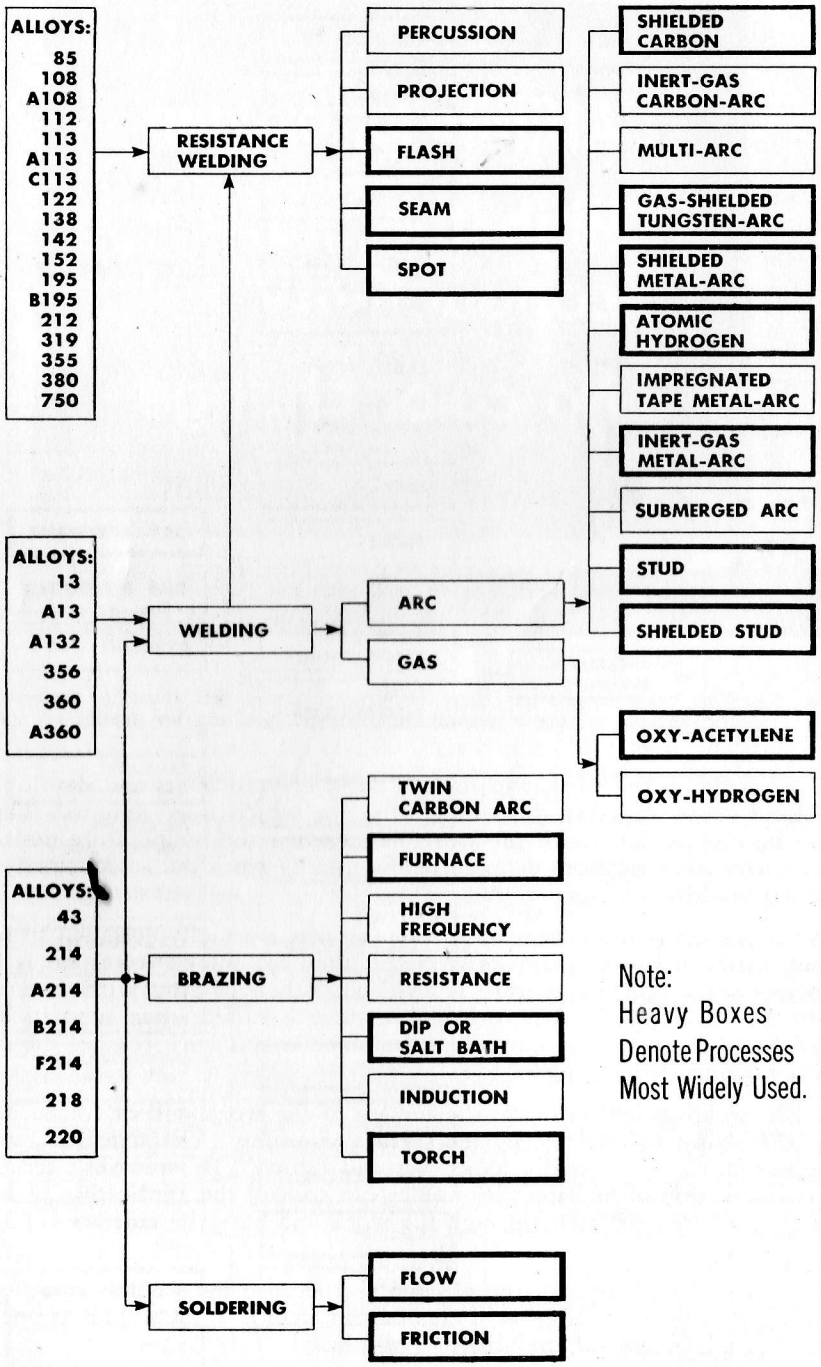
One of the most practical methods is to use specially designed crayons which melt at specific temperature values. Called "Tempilstiks", they can be obtained for almost any specific temperature in small increments. A

Processes Suitable for Joining WROUGHT ALUMINUM ALLOYS



Note:
Heavy Boxes Denote Processes Most Widely Used.

Processes Suitable for Joining ALUMINUM CASTING ALLOYS



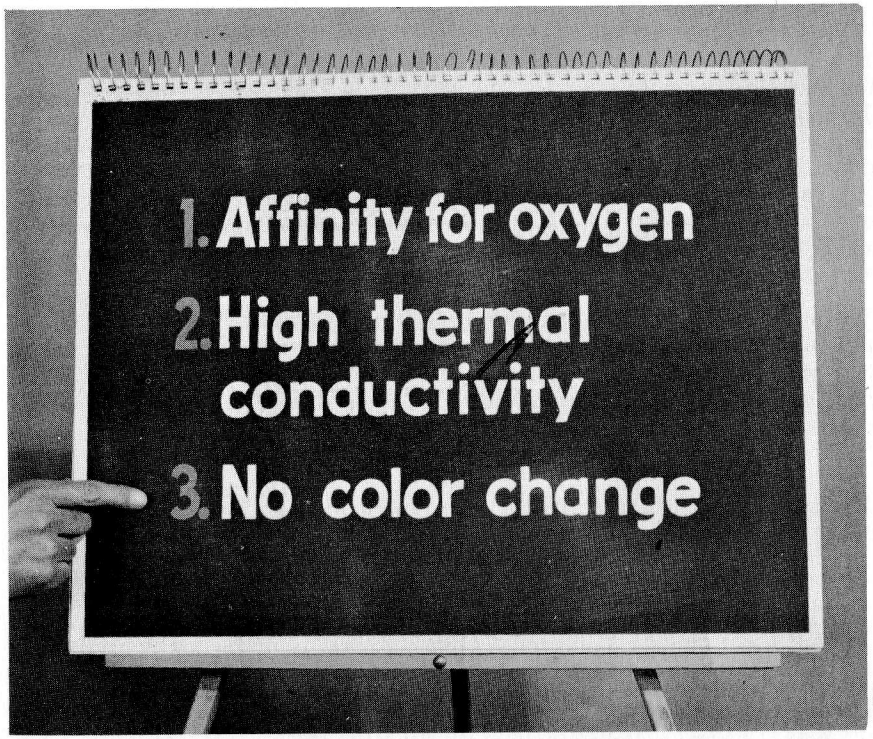


Fig. 5 — This chart emphasizes three important factors that must be understood for efficient joining of aluminum members. See text for details.

mark made on the work with one of these crayons melts and develops a "liquid" appearance at the temperature for which it is designed. These can be used to tell when the work has reached the temperature desired, although other methods detailed below usually work out satisfactorily in actual practice.

When soldering aluminum with flux, the flux is usually designed to first melt as the work temperature is raised; then to "smoke" or fume as the correct soldering temperature is attained. When brazing with flux, the flux first dries out as the work temperature is raised; then it melts and assumes a characteristic "liquid" appearance as the work reaches the correct brazing temperature.

When welding with a torch, the surface of the work will of course melt first. Melting is indicated by the surface assuming a characteristic "wet" appearance . . . . it actually looks wet and "shiny". By watching for this first indication of melting, the welder can control the application of heat so that he does not melt through the work and have the entire weld area drop away.

This is no problem with the electric arc because the weld is completed so fast that the adjoining weld area has no chance to melt. This is one of the big advantages of the arc.

PROPER MECHANICAL SUPPORT

Certain aluminum alloys have constituents which melt as low as 900°F. This means that in furnace brazing, for example, where the entire piece is brought up to temperatures around 1100°F, proper support must be given the entire work piece to prevent warping and distortion. Wherever any considerable area of the work is raised much above 900°F, it is important to be sure that the aluminum alloy used has sufficient mechanical strength to be self-supporting. If it does not, an adequate system of mechanical supports must be provided.

The above factors are what makes aluminum different from other metals. But once these easily understood characteristices are kept in mind, it is easy to see why aluminum can be welded, brazed, and soldered so sucessfully. In fact, some processes today are available which make joints in aluminum faster and at lower cost than in other metals.

The chart, Fig. 5, highlights the three main factors that must be remembered in joining aluminum:

— its affinity for oxygen
— its high thermal conductivity
— no color change at elevated temperatures

Now that we understand the important characteristics that make the joining of aluminum different from other metals, let's examine the modern techniques engineers and metallurgists of the welding industry have developed for soldering, brazing, and welding this light metal.

WELDABILITY RATINGS

As you know, aluminum is not a single metal but a whole family of metals known as "aluminum alloys". These may have as many as six or more other elements added to the aluminum, in addition to the small amounts of certain elements always present as impurities. These alloys vary in their ease of welding, brazing, and soldering because the addition of other elements influences their joining characteristics.

Also, aluminum parts can be classified as to whether they are made from wrought aluminum alloys or cast aluminum alloys. Wrought aluminum parts include items made from sheet, plate, wire, rod, bar, tubing, pipe, extrusions, forgings, and rolled shapes. Cast aluminum parts may be made by sand casting, permanent-mold casting, or die casting as well as by other less well known casting processes. Therefore two separate tables of Weldability ratings are shown . . . . for wrought aluminum alloys on Page 11, and for the casting alloys on Page 12.

Also because the alloy content influences the type of joining process, two separate supplementary charts are shown to indicate processes most suitable for particular wrought alloys, Page 7, and casting alloys, Page 8. Here, as in the main process chart, Fig. 1, those enclosed in heavy lines are the processes most widely used.

WELDABILITY RATINGS FOR WROUGHT ALUMINUM ALLOYS (1)

Alloys (2)	Resistance Welding	Pressure Welding	Gas Welding	Arc Welding With Flux	Arc Welding with Inert Gas	Brazing	Soldering
EC	B	A	A	A	A	A	A
1100	C	A	A	A	A	A	A
2011	B	D	D	D	D	D	X
2014	D	. . .	D	B	C	D	X
2017	D	D	D	B	C	D	X
2024	D	C	D	B	C	D	X
3003	C	A	A	A	A	A	A
3004	C	A	B	A	A	B	B
5005	A	n.a.	C	C	A	A	n.a.
5050	C	A	A	A	A	B	B
5052	C	A	B	A	A	C	C
5083	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5086	. . .	. . .	. . .	. . .	. . .	. . .	. . .
5154	A	A	B	A	A	C	D
5357	. . .	. . .	. . .	. . .	. . .	. . .	. . .
6053	A	C	A	A	A	A	A
6061	A	C	A	A	A	A	A
6062	A	C	A	A	A	A	B
6063	A	C	A	A	A	A	B
7075	B	D	D	D	C	D	D

(1) Ratings in the columns are defined as follows:
- A: Generally weldable by all commercial procedures and methods.
- B: Weldable with special technique or for specific applications which justify preliminary trials or testing to develop welding procedure and weld performance.
- C: Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.
- D: No commonly used welding methods have so far been developed.
- X: Indicates soldering is not recommended.

(2) Ratings given apply to the annealed temper in all cases. The harder tempers will have slightly better ratings as far as the resistance welding process is concerned, and somewhat lower ratings as far as pressure welding is concerned.

WELDABILITY RATINGS FOR ALUMINUM CASTING ALLOYS

ALLOY	RELATIVE WELDABILITY RATING(1)					
	Gas Welding	Arc Welding	Resistance Spot & Seam Welding	Brazing	Soldering	
					Flow	Friction
SAND CASTING ALLOYS						
43	A	A	A	B	B	A
108	B	D	B	X	D	A
112	B	B	B	X	D	A
122	C	B	B	X	X	A
142	C	B	B	X	D	A
195	C	B	B	X	D	A
212	B	B	B	X	X	A
214	B	A	B	X	B	A
220	D	C	B	X	B	A
355	A	A	A	X	C	A
A355	A	A	A	X	C	A
356	A	A	A	X	B	A
PERMANENT-MOLD CASTING ALLOYS						
43	A	A	A	B	B	A
A108	A	A	A	X	D	A
B113	B	A	B	X	D	A
C113	B	A	B	X	D	A
122	D	C	B	X	X	A
A132	D	C	C	X	D	A
138	D	C	C	X	X	A
142	C	B	B	X	D	A
B195	C	B	B	X	D	A
A214	B	A	B	X	B	A
355	A	A	A	X	C	A
356	A	A	A	X	B	A
DIE-CASTING ALLOYS						
13	D	D	D	X	C	A
43	B	B	C	A	D	A
85	D	D	D	X	D	A
218	D	D	D	X	B	A
360	D	D	D	X	B	A
380	D	D	D	X	D	A

(1)Relative Weldability Rating "A" = Excellent, "B" = Good, "C" = Fair, "D" = Poor, and "X" = Not recommended.

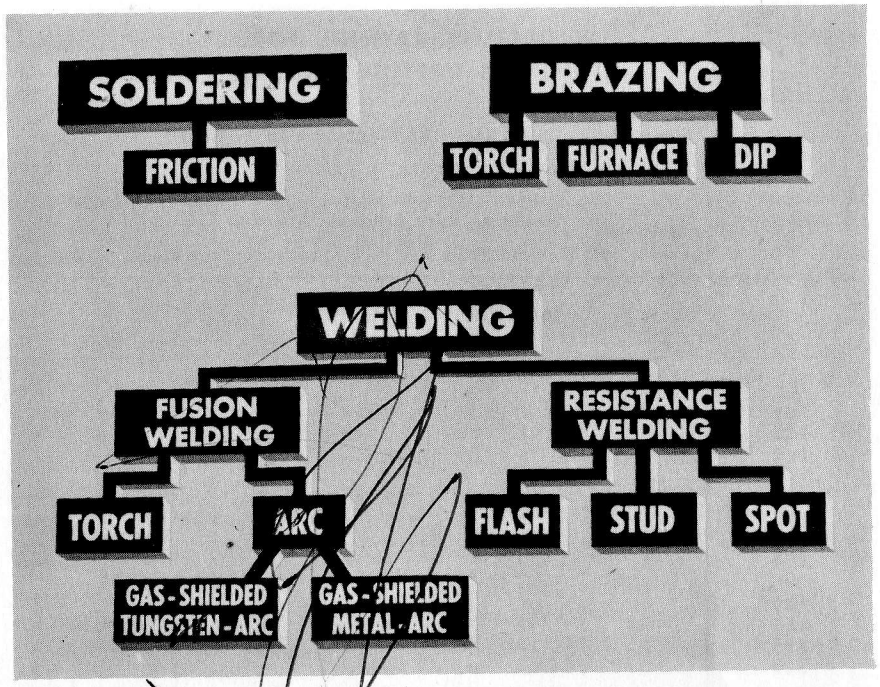


Fig. 6 — The most widely used methods for joining aluminum are indicated in this chart. These processes are described in the accompanying text.

FRICTION SOLDERING

Most practical method developed to date for soldering aluminum is friction soldering, using a glass fiber brush. As in soldering all other metals, the base metal is not melted. The first and most important step is to coat the aluminum with solder . . . . known as a tinning operation in which the aluminum oxide film is removed and replaced by a layer of solder.

To do this, the work is heated up to soldering temperature . . . . the point where the solder will melt when applied to the aluminum surface. Enough solder is then melted on the aluminum surface to tin it. A glass fiber brush is now applied down through the overlying layer of molten solder and the surface to be tinned thoroughly scrubbed. Of course, there must be enough molten solder available to cover the area to be tinned. The sharp ends of the glass fibers break up the aluminum oxide film and permit the molten solder to bond directly to the underlying aluminum. The pool of molten solder prevents the air from re-forming the oxide film. See Fig. .

The characteristic that makes the glass fiber brush so effective in this operation is that it does not absorb heat and freeze the molten solder. On the other hand, wire brushes or other metal abrading tools used to

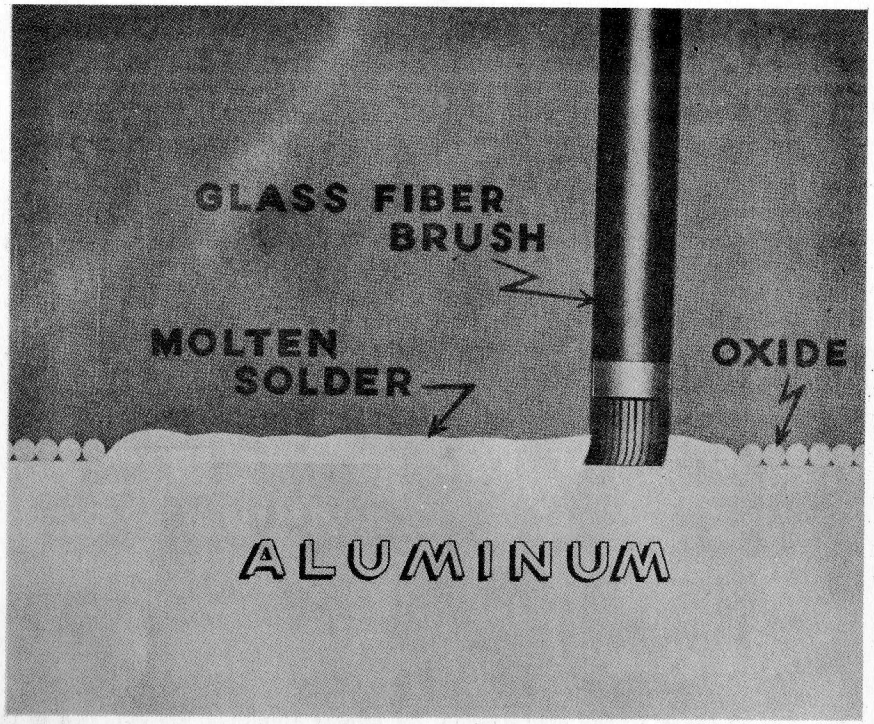


Fig. 7 — The fastest, simplest, and best method for soldering aluminum parts is diagrammed here. The glass fiber brush is worked down through molten solder layer to remove oxide film and "tin" joint surfaces.

remove the oxide film quickly freeze the solder and so are not recommended.

Once the surface of the aluminum parts has been tinned with the glass brush, it is easy to complete the soldered joint by heating both parts and flowing more solder into the joint where additional metal is required.

FLOW SOLDERING

Conventional soldering methods rely upon a suitable flux to dissolve or react to remove the oxide and to exclude the air to prevent reoxidation. Various types of aluminum fluxes and solders are available and work well when recommended techniques are followed. Certain assemblies are also soldered by dipping in a bath of molten solder. Whenever flux is used, care must be taken to remove any remaining flux after completion of the joint.

In aluminum, as in other metals, soldered joints should not be relied upon for mechanical strength . . . . but used to seal a joint or to assure good electrical connection between parts. Where mechanical strength is required, rivets or other mechanical connections such as roll seaming should be employed.

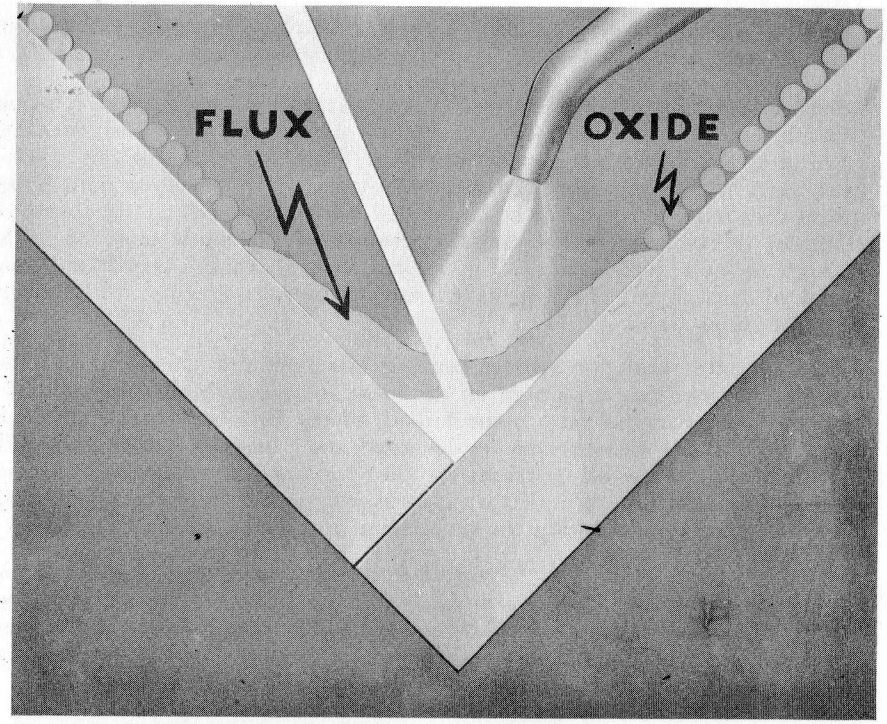


Fig. 8 — In torch brazing, flux removes oxide film and keeps it from re-forming. Brazing alloy is melted to flow under flux and bond to surface of base metal as is shown here.

BRAZING

Another method of joining aluminum parts is by brazing. This is similar to soldering in that the base metal is not melted. Instead, a high-strength aluminum alloy (the brazing metal) is flowed into the joint, making a connection that has considerable mechanical strength . . . . almost as strong as a weld. The three most common methods of aluminum brazing are the torch, furnace, and dip processes. These differ only in the method of supplying heat. In all three, a flux is employed to remove the oxide film and to prevent it from re-forming.

Torch Brazing: Here a liquid flux is applied to the surfaces to be joined. The work is heated, drying out the flux which changes into a white powdery looking substance. As additional heat is supplied, the flux melts, indicating that the work has reached the correct temperature for brazing. The flux thus does three things . . . . dissolves the oxide film at the joint area, forms a liquid cover preventing the film from re-forming, and then indicates correct brazing temperature by melting to give a "wet" appearance.

At this point, the brazing alloy is flowed into the joint, displacing the flux at the metal surface and bonding directly to the base metal. See

Fig. 8. The brazing process differs from soldering by being done at a much higher temperature and by producing a much stronger joint.

Furnace Brazing: While torch brazing is seldom mechanized and is thus mostly a hand operation with limited production potential, furnace brazing is ideal for high production work. Heat is applied to the assembled parts as they pass through a furnace on a chain conveyor belt. This means that temperatures can be controlled with precision . . . . an absolute necessity in brazing because the temperature of the work must be high enough to melt the brazing alloy but not so high that it melts the base metal of the parts. This means narrow temperature range (20-50°F.) must be maintained.

To prepare the work for furnace brazing, parts are first chemically cleaned. Then a paste flux is painted on the joint areas and the brazing material placed between the parts to be joined, in the form of pre-cut strip or wire clips. These elements are so designed and positioned that they will melt and flow into all portions of the joint when the work reaches brazing temperature. Weights or clamps are usually added to hold the parts in correct position and to keep them in contact during brazing.

Sometimes the brazing alloy is supplied as a clad layer on the parts themselves. This greatly facilitates making joints which otherwise might be inaccessible. Heat exchangers such as used in air conditioners and heater units are examples of products using clad material to supply the brazing material at many joints simultaneously.

After going through the heating and cooling zones in the furnace, the work passes through a washer to remove all traces of flux. Thorough washing and rinsing is necessary to prevent any possibility of subsequent chemical reaction from traces of flux.

Furnace brazing is especially suitable for making long continuous joints, like those between tube and sheet in refrigerator evaporators. Such brazed joints are characterized by smooth fine-appearing fillets that require no grinding or finishing. Many joints can be made simultaneously in a single assembly and inaccessible locations involve no problem.

Dip Brazing: Like furnace brazing, dip brazing is a high production process which can make hundreds of joints in an assembly at one operation. Here, too, joints can be made at inaccessible locations just as easily as at outside corners. Before putting the parts together for the assembly, all dirt and oil is removed by running through a vapor degreaser. A molten salt is used as the heating medium. The salt also supplies the fluxing action, eliminating the need for a separate fluxing operation.

In most dip brazing work, the brazing material is provided at the joint in the form of a clad layer on the surface of the aluminum parts themselves. This eliminates the necessity of inserting separate pieces of brazing alloy at each joint and greatly facilitates making internal or otherwise inaccessible joints. Proper jigs and fixtures ensure intimate contact at the joint areas.

Assemblies are preheated in an air furnace to 1000°F. to remove moisture and to avoid freezing of the salt when the parts are submerged in the salt bath. This also reduces the heat load on the salt bath and makes it

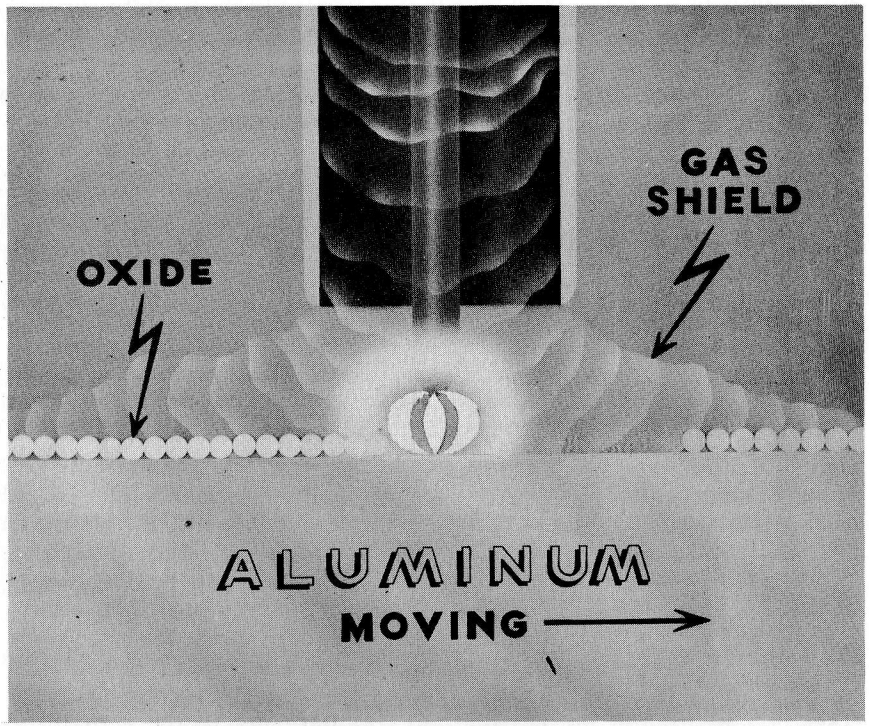


Fig. 9 — In gas-shielded arc welding, heat from the electric arc vaporizes the oxide film and a blanket of inert gas prevents it from re-forming. Heat of arc also melts weld metal rapidly, making welds at a fast rate. This diagram does not show weld metal.

easier to hold precise brazing temperatures. Transfer from the furnace to the salt bath must be rapid because most assemblies will lose heat fast enough to drop their temperature 100°F. each minute.

Before going into the salt bath, the assembly is placed on a rack which holds it at a compound angle to avoid trapping air as it is lowered into the bath and to facilitate drainage of the salt when the assembly is lifted out of the bath. Good drainage is necessary to hold drag-out losses to a minimum and reduce washing time.

As the molten salt penetrates the entire assembly, it fluxes all joint areas, assuring proper flow of the brazing alloy into all portions of the joints. The temperature of the molten salt is easy to control so that it melts the brazing material but not the aluminum parts themselves.

FUSION WELDING PROCESSES

It is well to remember that there is a considerable difference between brazing and welding. Brazing is done at a much lower temperature, adding filler metal, *without melting the base metal.* In welding, on the other hand, filler metal may or may not be added, but *the base metal is always melted.* Welding produces a much stronger joint than brazing.

Torch Welding: Possibly the oldest process for joining aluminum is torch welding. It is still one of the most popular of the welding methods for repair work. However, like torch brazing, it does not lend itself readily to mechanization and so finds little use in production work. It depends almost entirely upon the skill of the operator.

Flux is usually painted on the aluminum surface weld area and also applied to the welding rod itself. The flux removes the oxide film from the joint area and prevents the film from re-forming. It is important to use either a neutral or a reducing flame on the torch to avoid oxide problems. A simple puddling technique is employed by the welder to work the oxides and impurities up out of the weld metal and to lay a smooth, uniform bead.

Gas welding is most widely employed for joining thin aluminum sheet because the torch makes it easy for the welder to put as much heat as needed exactly where he wants it. After welding is completed all adhering flux must be carefully removed.

Arc Welding: The most popular and efficient method of joining aluminum is arc welding. The welding speed is faster and the concentrated heat of the arc tends to prevent distortion. The use of flux is eliminated because modern arc welding processes utilize the intense heat of the arc to vaporize the oxide coating. To prevent it from re-forming, today's modern equipment employs inert gas fed into the weld area to exclude the atmosphere. See Fig. 9. These processes are known as inert-gas-shielded arc welding.

There are two types . . . . one employs a tungsten electrode to strike an arc against the work. The other uses a consumable metal wire electrode instead of the tungsten electrode. The shielded tungsten-arc method is highly advantageous for joining many aluminum assemblies. But for high-production work, the gas-shielded metal arc is unexcelled.

Shielded Tungsten Arc: In this method, an arc is struck between a tungsten electrode and the work. Either filler metal is fed into the weld area . . . . or base metal is melted to produce the joint. An operator familiar with torch welding other metals can quickly learn to use the shielded tungsten arc because with one hand he applies the heat (as with the torch) and with the other hand he adds filler metal when needed, just as in torch welding. The weld bead is easy to control and is always smooth and uniform, so it requires no grinding or other finishing. The arc length is not critical, so it is easy for the operator to strike the arc and maintain it while making the joint. Metal is added when it's needed . . . . and flowed where it's wanted. In certain types of joints, it is not necessary to add filler metal . . . . as flanges or metal at the joint is simply melted down by the arc.

Shielded tungsten-arc welding, also known as Heliarc welding, is ideal for producing gas-tight joints, for making smooth fillets, for joining all types of aluminum parts quickly and easily. It produces a high quality weld with ease and speed. Technique is simple. Any welder can quickly learn this method. "Tig" welding is tungsten-inert-gas welding.

Shielded Metal-Arc Welding: This process is similar to the gas-shielded tungsten arc in that here again the heat of the electric arc is employed to vaporize the oxide film and a protective envelope of inert gas shields the weld area to prevent the oxide film from re-forming. Instead of the tungsten electrode, however, a wire electrode is fed continuously through the welding gun and melted off to supply the weld metal. The operator merely positions the welding gun at the point where the weld is to be made, pulls the trigger, strikes the arc, and moves the gun along the joint to lay down the weld metal.

The whole operation thus is extremely simple, fast, and very flexible. Vertical and overhead welds are made as easily as horizontal welds. By selecting appropriate wire sizes and welding currents, small or large weld beads can be produced as desired.

This is the process most widely used today for welding aluminum. It not only is exceptionally versatile but produces a smooth, even bead of weld metal that requires little or no finishing. Since no fluxes are used, there is never any slag to be cleaned off the finished piece.

With this equipment, welding aluminum becomes actually easier and faster than welding other metals with conventional equipment. Too, this process lends itself readily to mechanization and many completely automatic setups are in use today, producing quality welds in aluminum at amazing speed and low cost. This process is the one to investigate wherever any aluminum welding is to be done in metal other than thin sheet. As will be pointed out below, spot or seam welding is usually recommended for the production welding of sheet aluminum.

The Shielded Inert-Gas Metal-Arc process (sometimes called Sigma) has proved the greatest contribution to the welding of all aluminum forms other than sheet. It is ideal for all structural work, for joining electrical bus bars. for tubing and pipe, and for assembling such items as curtain walls for buildings. "Mig" welding is metal-arc, inert-gas welding.

Special equipment developed by Reynolds and Air Reduction Company for field welding of cross-country oil and gas pipelines utilizes this process to make gas-tight circumferential welds at low cost. In fact, this process has so reduced the cost of laying aluminum pipe lines that they have become competitive with steel for many locations. In these setups, the machine automatically goes around the pipe, making as many passes as required to complete the joint. This allows miles of pipe to be joined in one, continuous piece.

The gas-shielded metal-arc hand gun is the ideal tool for many production welding requirements because it is extremely fast, simple to operate, and completely versatile. Once the equipment is set up and controls adjusted, the operator simply positions the gun, and pulls the trigger.

The difference between the tungsten-arc gun and the metal-arc gun is that with the tungsten arc, the operator controls the flow of metal with the arc, adding metal only when and where needed. On the other hand, the metal-arc gun lays down metal continuously at a fast, uniform rate.

Coated Rod: But suppose for a minute that your shop has been doing metal-arc welding of ordinary metals and that you have none of the special equipment described above for welding aluminum. You can still arc weld aluminum simply by selecting a coated rod of the correct type. Here again, the intense heat of the arc vaporizes the oxide film which

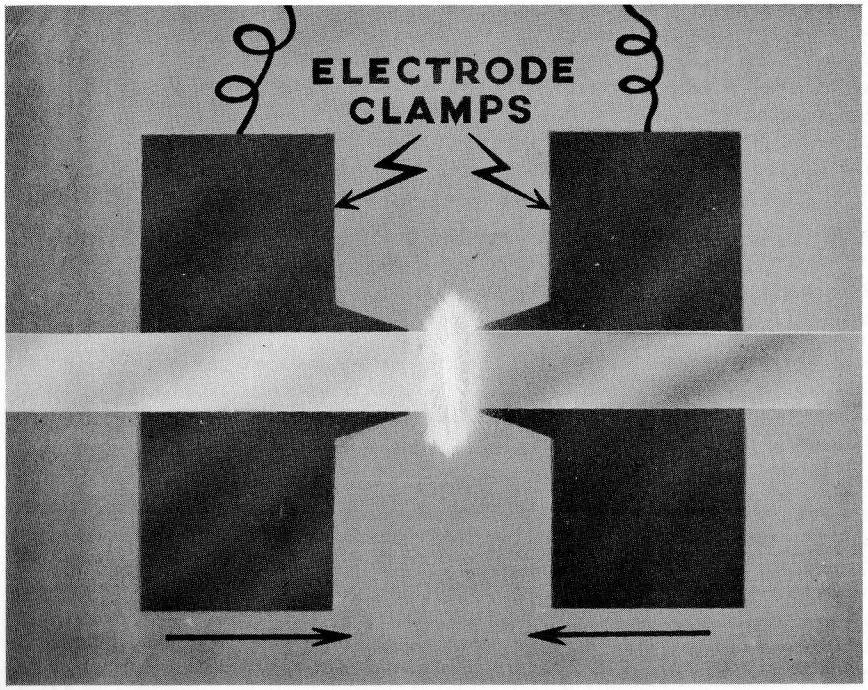


Fig. 10 — Flash welding pieces end-to-end by producing arc between them to vaporize oxide film, wet the weld interfaces, and soften adjoining metal. Fig. 11 shows completion.

is then kept from re-forming by the gas envelope created by burning the coating on this special aluminum-welding rod.

Thus with your existing equipment, and just by selecting the correct coated rod, you have a practical and effective method of making good joints in aluminum structures. Of course, if you have much aluminum welding to do, it will well pay you to obtain inert-gas-shielded arc welding equipment specially designed for use with aluminum.

RESISTANCE WELDING

All welding processes discussed up to this point are known as "fusion" welding processes. In addition to these, there is an entirely different group called "resistance" welding. In this group are flash welding, stud welding, and spot welding. Flash welding is recommended for butt welding end-to-end tubing, pipe, rod and bar as well as extruded or rolled sections. Stud welding is butt welding a solid section endwise to the flat surface of sheet or plate. Spot welding is used to join sheet to sheet, or sheet to any other section at any point on the surface.

In these processes, all of the elements that enter into making the weld are automatically controlled, and all the processes lend themselves to high speed production.

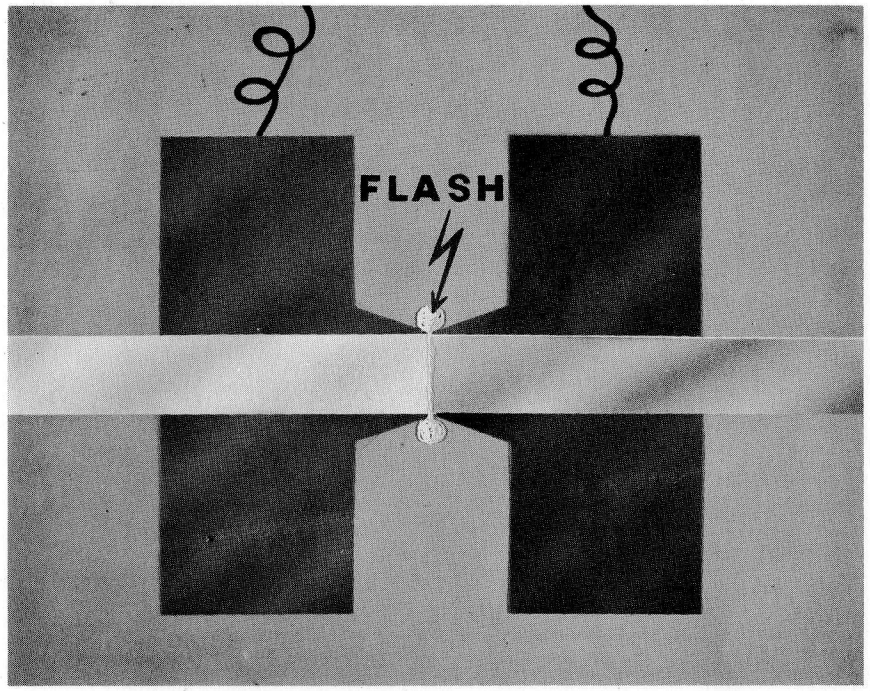


Fig. 11 — At correct point, electric current is cut off and action in Fig. 10 completed by forcing the two pieces together to squeeze out excess metal. This "flash" is cut to a thin fin by the chisel action of the dies as they close. Simple trimming operation then removes all trace of excess metal.

Flash Welding: First let's look at flash welding where similar sections are butt welded end-to-end. As shown in Fig. 10, the two pieces to be joined are held in separate electrode clamps and brought together. As they touch, an electric current flows from one to the other to produce an electric arc and vaporize the oxide coating. As arcing continues, it melts the ends of the two parts to be joined, wetting the interfaces and softening the metal near the ends.

As soon as enough metal has been melted off to be sure all oxide and other impurities have been vaporized and the weld area made plastic, the current is cut off and the two parts are upset by forcing together at high speed. This final push-up joins the two surfaces and forces the excess plastic metal out of the weld.

As shown in Fig. 11, the dies gripping the work can be given chisel points so that in the final push-up they act to almost completely cut off the flash . . . the metal squeezed out of the weld . . . leaving only a thin fin. This is an important advantage when flash welding aluminum as it means a simple trimming operation then easily removes the fin, leaving a completely smooth weld. This pinch-off is done automatically as the dies close. Since all the other operations are under complete automatic control, this process is exceptionally fast. Once the parts are placed in the

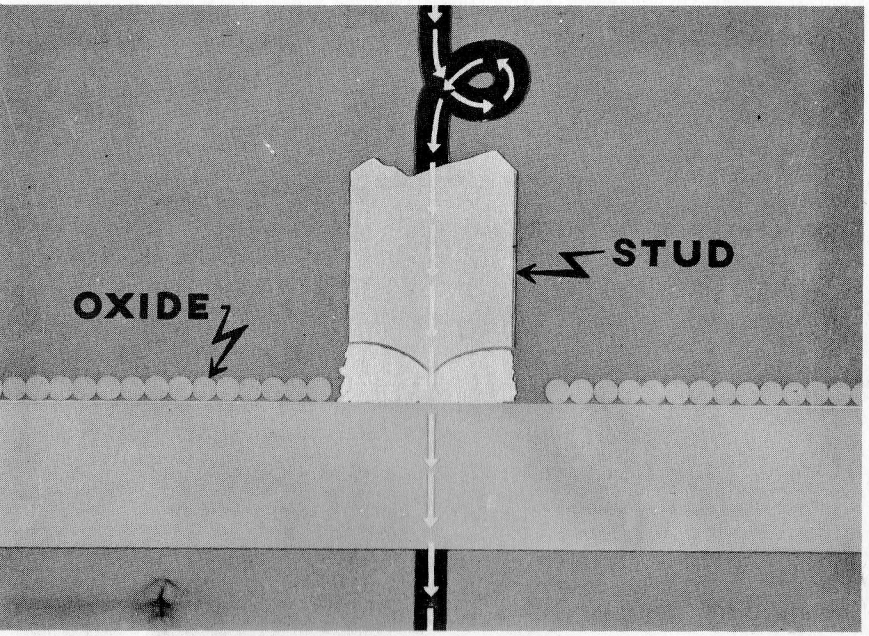


Fig. 12 — In stud welding, arc is struck between pointed end of stud and flat work surface, vaporizing oxide film and melting metal at weld interface.

electrode clamps, the entire welding sequence proceeds automatically to complete the weld in a few seconds.

Flash welding is suitable not only for joining aluminum to aluminum but also for joining aluminum to other metals. For example, a short length of aluminum tubing can be joined to a short piece of copper tubing by this method to make fittings for aluminum refrigerator evaporators.

Another typical flash welding job is the joining of extruded aluminum members to make window frames. It is easy to make accurate 90° joints to precise dimensions with this process. Flash welds develop 90-95 percent of the strength of the original material.

Stud Welding is actually a specialized type of flash welding in which an aluminum stud (it can be a bolt, screw, or similar device) is attached endwise to any flat aluminum surface. Most stud welds are made with a hand gun, which makes it possible to place a stud at any point on a large surface. The action is so fast that it's impossible for the eye to see what takes place. But here's how it works:

The stud is first positioned in the end of the welding gun. The three tripod-type legs of the gun are then pushed against the surface of the work with the stud just over the point of attachment. As the operator pulls the trigger of the gun, the stud moves down to contact the work. The end of the stud is cone-shaped. As the tip contacts the work surface, an electric current flows, producing an electric arc. See Fig. 12. This arc vaporizes the oxide film and instantly melts the surfaces to be joined to fusion temperature. As the stud continues to move down, the current

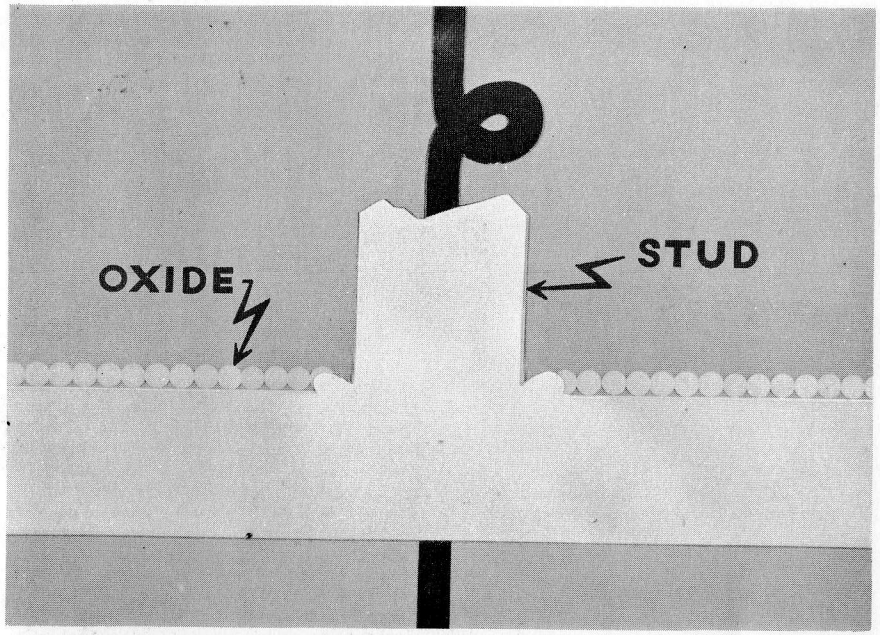


Fig. 13 — Stud is forced against flat surface as current is cut off to complete the action, squeezing out excess weld metal and consummating the weld.

stops, the metal freezes, and there is the completed weld . . . . faster than the eye can follow. See Fig. 13.

This process is ideal for attaching a bolt, rivet, or screw to any flat aluminum surface. It is widely used for attaching insulation for construction of bulkheads and room dividing partitions aboard ship, and similar applications.

Spot Welding: The third resistance welding process to be discussed is spot welding. The main difference between the techniques used in spot welding aluminum and spot welding other metals is caused by aluminum's higher electrical conductivity and the fact that aluminum has a narrow plastic range within which the weld must be made.

All aluminum alloys can be spot welded. First, however, the surface must be prepared by cleaning, de-greasing, and de-oxidizing. Chemical processes are recommended, although mechanical abrasion (use of sand paper, wire brush, or the like) can be used. For all production work, chemical cleaning and de-oxidizing are essential for uniform weld quality. Going through a series of baths partially dissolves the oxide surface or whittles it down, so to speak, to a thin film that is easily penetrated by the welding current. This thin oxide film then is left on the metal as a protection against re-oxidation.

To be sure that the proper thickness is produced by the chemical treatment, the oxide film is checked by measuring its electrical resistance. This provides a quick accurate check that ties in directly with the welding operation itself.

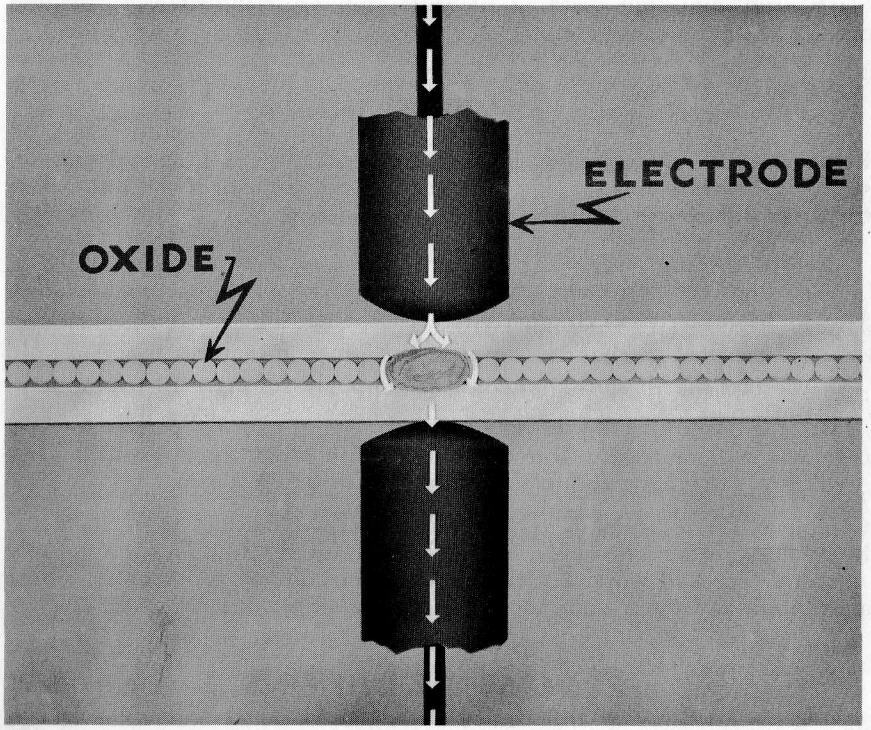


Fig. 14 — In spot welding, resistance to flow of electric current melts nugget to form joint. Most of oxide has previously been removed by chemical treatment. Current easily penetrates remainder.

After proper surface preparation, the two parts to be joined are placed on the bottom electrode of the welding machine at the point where the weld is to be made. The upper electrode is then moved down to contact the work and apply correct pressure. Spot welding makes use of the fact that electric current flowing through a metal heats it.

As shown in Fig. 14, a sudden pulse of electric current is then passed through the work, breaking down the thin oxide film and melting the two sheets at the interface to form a nugget of molten metal between the two parts being joined. The nugget grows as the current continues. The duration of the flow of current is accurately timed and cut off as the desired nugget size is reached, bonding the two parts together. There is no arc. A sudden single pulse of electric current does the entire job in a split second.

Spot welding is exceptionally versatile. It is widely employed in making all types of sheet metal assemblies. The only difference between spot welding aluminum and spot welding other metals is the fact that aluminum is a better electrical conductor, so more electrical energy must be put into the aluminum weld. For this reason, aluminum spot welders are larger machines with greater electrical capacity than similar machines welding comparable assemblies of older metals.

Flash, stud, and spot welding of aluminum are handled as easily and rapidly as in any other metal.

SUMMATION

Remember . . . . aluminum welding is not difficult, it's just different. Or saying it another way . . . . it's different . . . . not difficult. Once you allow for these differences:

— its affinity for oxygen (the oxide film)
— its high thermal conductivity
— its high electrical conductivity
— its need for mechanical support at high temperatures
— the fact that it shows no color at temperatures even up to the melting point,

then you will be able to join aluminum with satisfactory results . . . . regardless of whether you are soldering, brazing, or welding.

Of course, there are many other joining methods besides those discussed here. These others, however, are of more limited scope or suitable only to special types of work. For further assistance on any problem in joining aluminum, call upon your local Reynolds representative.

PROCESS DEFINITIONS

The following are definitions of the various processes found in the chart, Fig. 1. These definitions are included here since some of the processes may not be familiar to the reader. Note that the term "Coalescence" used in these definitions denotes growing together to form a single body or continuous grain structure. A "weld" is a localized coalescence of metal.

Aircomatic: See "Inert-Gas-Shielded Metal-Arc Welding," Page 18.

Brazing, Dip: Coalescence is produced by heating in a molten salt bath . . . . same as "salt bath" brazing. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction (Page 16.)

Brazing, Flow: Coalescence is produced by pouring molten filler metal over the joint. Filler metal must melt above 800°F. and below base metal; is distributed through joint by capillary attraction.

Brazing, Furnace: Coalesence is produced by heating in a furnace. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction. See Page 16.

Brazing, Induction: Coalesence is produced by heat from resistance of work to flow of induced electric current. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction.

Brazing, Resistance: Coalesence is produced by heat from resistance of work to flow of electric current. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction.

Brazing, Salt Bath: Coalesence is produced by heating in a molten salt bath . . . . same as "dip" brazing. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction.

Brazing, Torch: Coalesence is produced by heat from a torch. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction.

Brazing, Twin Carbon-Arc: Coalescence is produced by heat from an electric arc between two carbon electrodes. Filler metal must melt above 800°F. and below base metal; is distributed in joint by capillary attraction.

Heliarc; Heliweld: See "Gas-Shielded Tungsten-Arc Welding", Page 18 in this booklet.

Sigma: See "Shielded Inert-Gas Metal-Arc Welding", Page 18.

Soldering, Friction: A soldering method for aluminum in which the aluminum oxide surface coating is broken by abrading the work surface through an overlying layer of molten solder. Solder then bonds directly to the underlying clean metal surface which is prevented from oxidizing by the layer of molten solder. See Page 13.

Soldering, Flow: A soldering method for aluminum in which the aluminum oxide surface coating is dissolved by appropriate flux, allowing the solder to bond to the base metal. See Page 14.

Welding, Arc, Atomic Hydrogen: Coalescence is produced by electric arc between two tungsten electrodes in a hydrogen envelope. Hydrogen provides shielding and aids heat transfer. Pressure and filler metal may or may not be used.

Welding, Arc, Submerged: Coalescence is produced by electric arc between bare filler metal electrode and work; shielded by blanket of granular, fusible material on work. No pressure. Filler metal may also be added from supplementary rod.

Welding, Carbon-Arc, Gas-Shielded: Coalescence is provided by electric arc between carbon electrode and work; with or without pressure and filler metal; shielded by inert-gas envelope.

Welding, Carbon-Arc, Shielded: Coalescence is produced by electric arc between carbon electrode and work. Shielding may be from combustion of solid material fed into arc or from flux on the work, or both. Pressure and filler metal may or may not be used.

Welding, Flow: Coalescence is produced by heating with molten filler metal poured over surfaces to be joined. Distribution of filler metal does not depend on capillary attraction.

Welding, Gas, Air-Acetylene: Coalescence is produced by gas flame burning acetylene in air; no pressure; with or without filler metal.

Welding, Gas, Oxy-Acetylene: Coalescence is produced by gas flame burning acetylene and oxygen; with or without pressure or filler metal.

Welding, Gas, Pressure: Coalescence is produced simultaneously over

Rabele-B/guilz-1970

entire area of abutting surfaces by heating with gas flame and applying pressure; no filler metal used.

Welding, Metal-Arc, Impregnated-Tape: Coalescence is produced by electric arc between filler metal electrode and work. Shielded by decomposition of impregnated tape wrapped on electrode as it is fed to arc.

Welding, Resistance, Upset: Coalescence produced by heat from resistance to flow of electric current from one abutting surface to other as light pressure is applied, followed by application of high pressure to "upset" metal at abutting surfaces.

Welding, Stud, Shielded: Coalescence is produced by electric arc between metal stud and work surface; shielded by inert-gas envelope; pressure always used. See Page 22.

Welding, Stud, Unshielded: Coalescence is produced by electric arc drawn between metal stud and work surface and subsequent application of pressure. No filler metal added. No shielding.

Welding, Tungsten-Arc, Gas-Shielded: Coalescence is produced by electric arc between tungsten electrode and work; with or without filler metal; shielded by inert-gas envelope. Also known as the "Heliarc" or "Heliweld" process. Also called "Tig" welding. See Page 18.

★ ★ ★

This book was written and produced by G. W. Birdsall, Director, Editorial Services, Reynolds Metals Company, Richmond 18, Va.

Adv. No. 802-21-9 (15M 63-OD)